

AD-A078 748

COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER NH F/G 13/8  
ANTIFREEZE-THERMODRILLING FOR CORE THROUGH THE CENTRAL PART OF --ETC(U)  
NOV 79 I A ZOTIKOV  
CRREL-79-24

UNCLASSIFIED

NL

| OF |  
AD-  
A078748



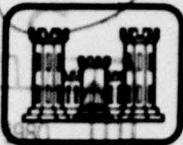
END  
DATE  
FILED  
I 80  
DDC

DDC FILE COPY

# CRREL

## REPORT 79-24

LEVEL II



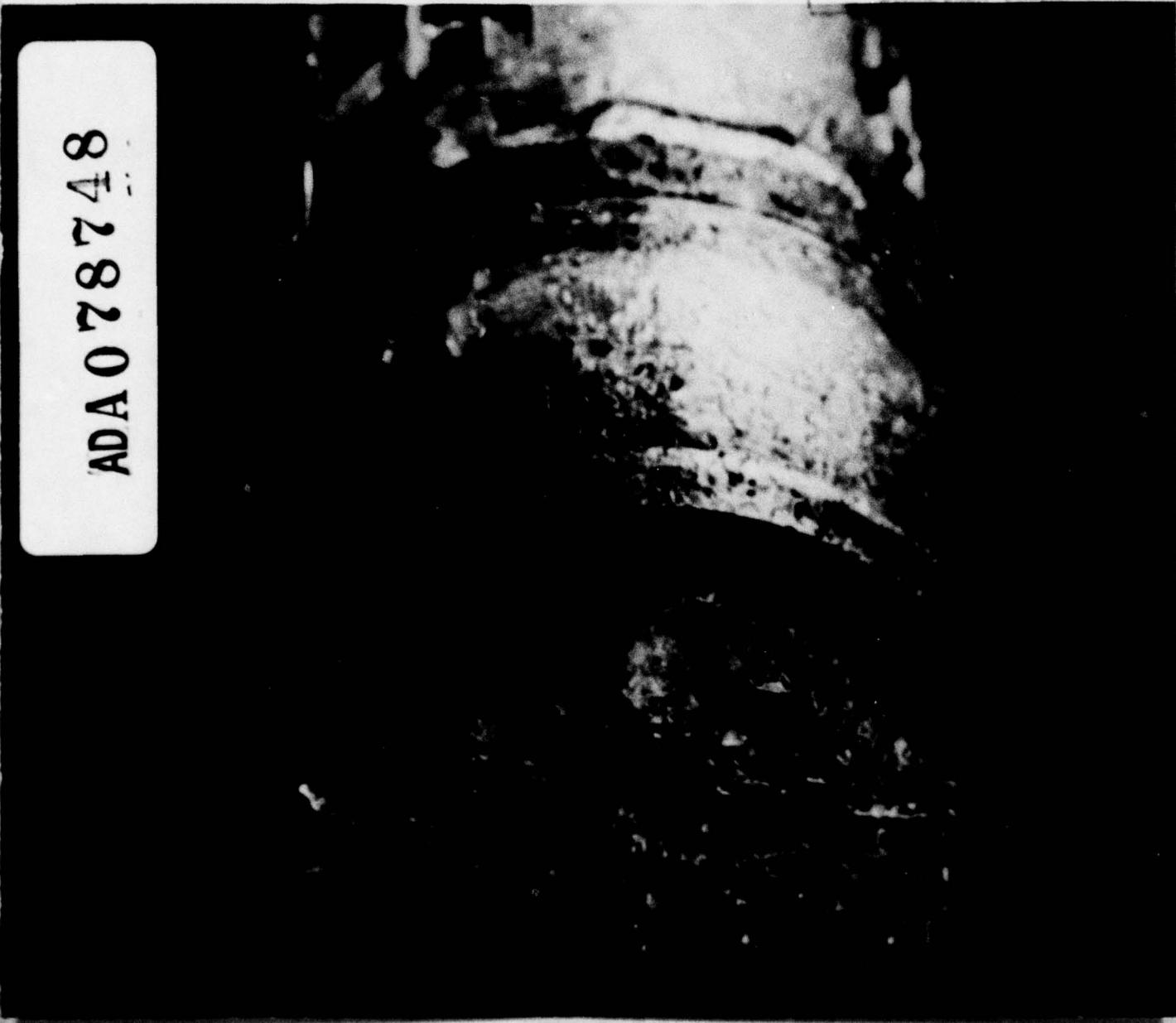
JAN 2 1981

DD FORM 1750-1  
REPLACES EDITION A  
1000 COPIES

*Antifreeze-thermodrilling for core through  
the central part of the Ross Ice Shelf  
(J-9 Camp), Antarctica*

DISTRIBUTION STATEMENT A  
Approved for public release;  
Distribution Unlimited

ADA078748



*For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

*Cover: Last core drilled at J-9 Camp showing waffle-like structure of the bottom ice. This ice is composed entirely of aligned crystals of sea ice formed by freezing of sea water directly to the bottom of the Ross Ice Shelf.*

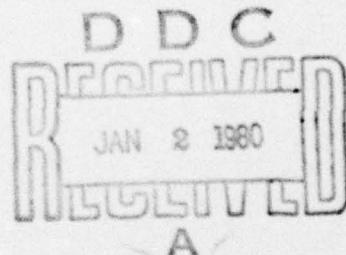
# CRREL Report 79-24



## *Antifreeze-thermodrilling for core through the central part of the Ross Ice Shelf (J-9 Camp), Antarctica*

Igor A. Zotikov

November 1979



Prepared for  
**NATIONAL SCIENCE FOUNDATION**  
By  
**UNITED STATES ARMY**  
**CORPS OF ENGINEERS**  
**COLD REGIONS RESEARCH AND ENGINEERING LABORATORY**  
**HANOVER, NEW HAMPSHIRE, U.S.A.**

Approved for public release, distribution unlimited

037100

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE			READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER CRREL Report 79-24	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) 6) ANTIFREEZE - THERMODRILLING FOR CORE THROUGH THE CENTRAL PART OF THE ROSS ICE SHELF (J-9 CAMP), ANT- ARCTICA		5. TYPE OF REPORT & PERIOD COVERED	
7. AUTHOR(s) 10) Igor A. Zotikov		6. PERFORMING ORG. REPORT NUMBER	
8. PERFORMING ORGANIZATION NAME AND ADDRESS Institute of Geography U.S.S.R. Academy of Sciences Moscow, U.S.S.R.		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 12) 17	
11. CONTROLLING OFFICE NAME AND ADDRESS National Science Foundation Washington, DC		12. REPORT DATE 11) Nov 1979 14) 1979	
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE	
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited. 14) CRREL-79-24			
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)			
18. SUPPLEMENTARY NOTES			
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Antarctic regions Drilling Ice Ross Ice Shelf Thermal drilling			
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) By using a new thermocoring technique, a hole was successfully drilled through the 416-m thickness of the Ross Ice Shelf at J-9 Camp. This report provides a description of the drill and an account of this drilling project. A provisional examination of the core shows the ice shelf to consist of 410 m of snow and glacial ice underlain by 6 m of sea ice formed by direct freezing of sea water to the bottom of the Ross Ice Shelf.			

## PREFACE

This report was prepared by Dr. Igor A. Zotikov, of the Institute of Geography, U.S.S.R. Academy of Sciences, Moscow, U.S.S.R., while he was a Visiting Scientist at the U.S. Army Cold Regions Research and Engineering Laboratory. Funding for this work was provided by National Science Foundation Interagency Agreement DPP 78-17165.

Donald Garfield, Herbert Ueda, Dr. Anthony Gow and Ronald Atkins of CRREL technically reviewed the manuscript of this report.

Accession For	
NTIS GRA&I	<input type="checkbox"/>
DOC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	<input type="checkbox"/>
By _____	
Distribution/	
Availability Codes	
Dist	Available and/or special
A	

# ANTIFREEZE-THERMODRILLING FOR CORE THROUGH THE CENTRAL PART OF THE ROSS ICE SHELF (J-9 CAMP), ANTARCTICA.

Igor A. Zotikov

## INTRODUCTION

In December 1978, core drilling through more than 400 m of the Ross Ice Shelf was performed as part of the Ross Ice Shelf Project (RISP). About 400 m of core with a diameter of about 8 cm was recovered, including a core from the very bottom of the ice shelf. This drilling was performed using portable equipment specially designed by the Arctic and Antarctic Research Institute in Leningrad (U.S.S.R.) in cooperation with the Institute of Geography, U.S.S.R. Academy of Sciences in Moscow.

This equipment differed appreciably from other equipment used for this kind of ice drilling. The history of development of this equipment and other thermodrilling equipment in the U.S.S.R. is not generally known. Therefore, description and history of development of this equipment will help to explain the philosophy of this new method of drilling which has proved so successful.

## HISTORY OF THERMODRILLING IN THE U.S.S.R.

The history of drilling in ice shows that the drilling is not as simple as it might appear. Heat

generated by mechanical cutting of the ice, friction of rotating pipe columns and the need to remove ice chips from the hole create many difficulties when conventional rotary drilling methods are used. Most important of these difficulties is the possibility of the pipes and chips becoming frozen in the hole. In the U.S.S.R., this problem was recognized as early as 1957 after a 560-m-deep hole had been drilled through the Antarctic ice sheet 5 km to the south of Mirny Station, using conventional drilling equipment.

The low melting point of ice has encouraged the use of thermal methods of drilling holes in ice by melting. This kind of drilling does not require the use of rotating pipes.

The first and simplest thermodrilling equipment used by the Soviet Antarctic Expedition was made in Antarctica (during the winter of 1958-59) by V.S. Ignatov at Vostok Station, I.A. Zotikov at Mirny and Komsomolskaya Stations and F.K. Kruchinin at Lazarev Station. This drilling equipment consisted of electrically heated, cylindrical, solid drilling heads (Ignatov 1960). Experiments have shown that this equipment usually drills holes in the Antarctic ice cover about 50 m deep without any difficulties but that drilling stops at this depth, which has been shown to always be close to the transition between firm and ice. When drilling through snow

and firn, the meltwater created by thermodrilling passes directly into the pores of the permeable firn and the hole remains water-free. Below about 50-m-depth, this water cannot permeate through the walls of the hole and the water remains in the hole. The heat source of the thermodrill in this case was located within the pool of melted water. Most of the heat was expended in warming up the water and increasing the diameter of the hole, instead of being used on downward drilling.

This experimental drilling showed that drilling a hole downward in solid ice by melting is possible by two methods:

1. Constantly taking all melted water from the hole.

2. Distributing heat sources within the thermodrilling head in such a way that the meltwater layer between the heated walls of the solid thermodrilling head and the walls of the hole is small enough to prevent strong thermal convection of the water and the subsequently large heat losses to warm the liquid column above.

Thermodrilling equipment using the first method (dry hole) was designed and made in the Leningrad's Institute of Mining by B. B. Kudriashov and others (Kovotkevich and Kudriashov 1974). Using this equipment, a core hole more than 900 m deep was drilled at Vostok Station.

Equipment using the second method was designed and fabricated in the Arctic and Antarctic Research Institute, Leningrad, under contract with the Institute of Geography, Moscow, by V. E. Morev (Morev 1966). With this equipment it has been possible to drill in a liquid-filled hole without dramatically increasing the diameter of the hole.

To obtain a core of the ice by either method, the heated thermodrilling head and the drilling column have used an annular shaped section long enough to house the core. To pump melted water from the hole and to store it, part of the drilling column must include a pumping device and water container.

The need to pump melted water from the bottom of the hole, to collect this water and the core, and to control the quantity of the water pumped out from the hole, etc., has resulted in a complicated and heavy drilling device. Still, it has proven satisfactory for drilling holes in polar ice sheets (Ueda and Garfield 1969, Kudriashov et al. 1973).

In 1965, design of a new drill was initiated that would drill holes and take cores from mountain

glaciers. Equipment for this work has to be portable and light.

Taking into consideration that many mountain glaciers are temperate ones (ice temperature is at or close to the ice melting temperature), V. A. Morev designed thermal drilling equipment which did not require the removal of any water from the hole; the drill consisted only of a thermal drilling head, core container pipe, and a core catching device. With this drill, melted water was left in the hole. This equipment was tested on temperate glaciers of the polar Ural and Pamir Mountains and performed satisfactorily.

## PHILOSOPHY OF ANTIFREEZE THERMODRILLING

Distinct differences exist between the thermodrilling equipment designed to remove water from the hole and the equipment without special devices for removing water. The drilling column in the second case is only half as long and much lighter than the column fitted with a device to remove meltwater from the hole. The cable for the thermal drill is much smaller in diameter because it is possible to use a single-conductor armored cable. All these improvements make the drilling winch and the mast smaller, simpler, lighter, and much safer.

Once the drill for coring in glaciers was developed the next step was to design simple equipment capable of drilling through cold or temperate ice sheets while using all the advantages of leaving the melt-water within the hole.

It had been hypothesized by analogy with core drilling in temperate glaciers that it should be possible to drill holes in cold ice, leaving melted water within the hole if some antifreeze liquid could be added to this water such that the freezing temperature of the solution of antifreeze and water was made equal to the temperature of the glacier ice. Experiments conducted by V. A. Morev and I. A. Zotikov at the arctic drifting ice island, Severny Polus ("North Pole"), have proven this hypothesis. It was shown too that the antifreeze should be added to the water at or close to the bottom of the hole. Many antifreeze liquids were tested, including ethylene glycol, isopropyl alcohol, and ethyl alcohol. Best results were obtained using ethyl alcohol in ice which is not too cold.

In 1972, V. A. Morev (Morev 1972) designed

and built new drilling equipment using this method of adding ethyl alcohol to the bottom of the drilled hole each time the drilling column was sent to the bottom of the hole for the next round of drilling. This method of drilling, in which melted water is left in the hole and prevented from freezing by adding ethyl alcohol to the water, has proven to be a satisfactory one. Using this technique many core holes have been drilled through mountain, arctic, and antarctic glaciers. The deepest core hole using this method was drilled to a depth of 800 m in 1977 near Novolazarevskaya Station, Antarctica (Morev and Raikovsky 1979). The same technique was also used to core-drill through the whole thickness of the Ross Ice Shelf in December 1978.

### THE DRILLING EQUIPMENT

The equipment used for the drilling through the Ross Ice Shelf consists of two main parts: 1) a thermal-drilling column, and 2) a winch with a mast and cable for supporting the column.

#### Thermodrilling column

The thermodrilling column (Fig. 1) was designed and built by V. A. Morev in the Arctic and Antarctic Research Institute, Leningrad, under contract with the Institute of Geography, Academy of Sciences of the U.S.S.R., Moscow. The main part of the body of the drilling column depicted in Figure 1 consists of a cylindrical pipe (1) made of stainless steel. It supports an electrically heated ring (2), which forms the lowest part of the column. The heated ring is connected to the pipe (1) with bolts and can easily be replaced. The ring consists of two copper cylinders hermetically welded together at the upper and lower ends of the ring. Between these cylinders is located the high resistivity wire used for heating the ring. Special electrical insulation is put between the wire and walls of the copper cylinders. Electrical power for heating is simple: one conductor is an insulated wire and the second conductor consists of the body of the drilling column, the armor of the cable and the body of the drilling winch. An inner pipe (3) with an open lower end is used both as a core barrel and as a container for the ethyl alcohol (antifreeze liquid). It is possible to use the same pipe for these two purposes because there is a piston (4) within the pipe which can be moved easily up and down.

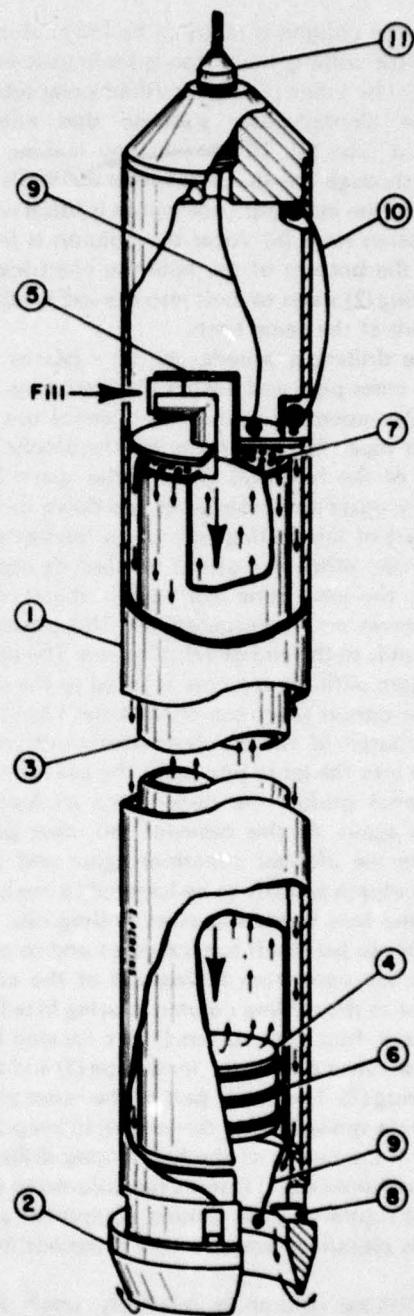


Figure 1. Cross section of antifreeze-thermodrilling tool (1. stainless steel outer pipe, 2. electrically heated ring, 3. inner pipe (core container or ethyl alcohol barrel), 4. piston, 5. pipe for filling inner pipe with alcohol, 6. compression rings, 7. holes, 8. core cutters, 9. electrical conductor, 10. spring-loaded device, 11. swivel device.)

When the column is ready to be lowered into the hole for drilling, the piston is set in its lowest position. The inner pipe (3) is filled completely with the alcohol-water solution that enters through a tube (5). To prevent any leaking of alcohol through the space between the walls of piston and the inner pipe, the piston is fitted with compression rings (6). After the column is lowered to the bottom of the hole the electrically heated ring (2) starts to melt into the ice, producing a core at the same time.

As the drilling proceeds, the core passes up into the inner pipe and pushes the piston up. As the piston moves, it pushes the alcohol out of the inner pipe. The only route for the alcohol is by way of the holes (7) through the space between the outer and inner pipes and down to the lower part of the drilling column to the bottom of the hole. When the piston reaches its upper position, the inner pipe will be full of ice core and it serves as a core container. This position corresponds to the end of a drilling run. The drilling column with the ice core is lifted to the surface. The core is taken out of the inner pipe and a new charge of the alcohol-water solution is pumped into the inner pipe until the pressure of the alcohol pushes the piston into its lowest position again. At this moment the inner pipe serves as the alcohol container again and the drilling column is ready to be lowered to the bottom of the hole to start another drilling run.

In order to break off the ice cores and to prevent the ice core from falling out of the core container as the drilling column is being lifted to the surface, four core cutters (8) are located between the lower part of the inner pipe (3) and the drilling ring (2). The upper part of the outer pipe (1) carries a spring-loaded device (10) to keep the column in the center of the hole during drilling.

A swivel device (11) fastens the column to the cable (9) supporting the drilling equipment and conducts electrical power to the thermodrilling ring.

The drilling column is relatively small and light; the diameter of the drilling column used for drilling through the Ross Ice Shelf is 103 mm and the external diameter of the heated drilling ring is 108 mm. The internal diameter of the ring is 80 mm, and the length of the core container pipe (3) is 260 cm. The overall length of the drilling column is 3.16 m.

The winch and the mast of the drilling rig used for drilling the hole through the Ross Ice Shelf were designed and made by V.S. Zagorodnov of

the Institute of Geography, U.S.S.R. Academy of Sciences, Moscow. The winch was made from aluminum alloys. The use of the one-conductor armor cable permitted the use of a smaller diameter cable, and because of this, the size of the winch was also made smaller. The winch with 600 m of cable attached, plus the mast and the drilling column, weighed less than 600 kg.

## DRILLING PROCEDURE

Part of the drilling procedure is already described above. This included filling of the inner pipe with alcohol solution until it was completely filled and the piston depressed to its lowest position. This solution was left in the bottom of the hole after each drilling trip. When calculating the theoretical concentration of the alcohol in the alcohol-water solution, account was taken of the fact that at each horizon the concentration of the solution at the bottom of the ice hole had to be just strong enough to prevent freezing of this solution when the temperature was equal to the temperature of the undisturbed ice. For this calculation we used the temperature-depth profile as measured by Clough and Hansen (1979). Actual concentrations, recorded in Appendix A, were not always equal to these calculated values. When slush in the solution within the hole started to form, the concentration was increased. When there were indications that the core and walls of the hole had started to dissolve, the concentration was decreased. It should be mentioned that the concentration of alcohol in this particular hole was always kept higher than the calculated values. A total of about 2000 liters of ethyl alcohol was needed to drill completely through the Ross Ice Shelf.

It should be noted that the concentration of alcohol steadily decreased with depth in the hole because of the increased ice sheet temperature with increasing depth (Fig. 2). This kind of temperature distribution within the thickness of the ice favors the use of alcohol to prevent freezing of water in the hole, because the density of the solution increases with the depth and the column of alcohol-water solution in the hole is stable. If the temperature of the ice decreases with depth, it is possible that the use of the alcohol as an antifreeze will create some complications because the density of the upper part of the solution column will be higher than that of the lower part of the column. It is reasonable to

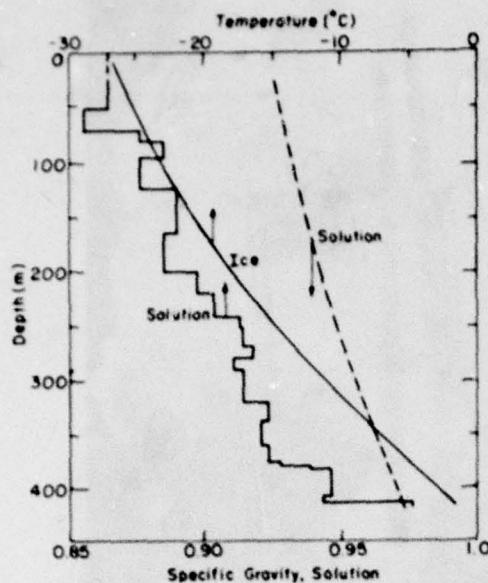


Figure 2. Ice temperature and specific gravity and temperature of the water-alcohol solution as a function of drilling depth in the Ross Ice Shelf at J-9.

expect vertical convection within the column under these conditions and the formation of slush within the hole.

The drilling rig was installed at J-9 Camp, Ross Ice Shelf, at the end of November 1978. The rig was located within a lightweight shelter; Figure 3 shows this rig when the drilling column, with a core, had just been lifted to the surface. Drilling began on 1 December. The first 30 m of the ice shelf were drilled in two days. All the meltwater in the top 30 m was allowed to disperse through the permeable walls of the hole and theoretically it would have been possible to drill a dry hole without alcohol under these conditions. However, alcohol was used to prevent possible complications in this part of the ice shelf. The concentration of the alcohol-water mixture put into the drilling column container was about 30%, just enough to keep this solution from freezing at the temperature of the undisturbed ice. Apart from some alcohol-soaked pieces, practically no core was recovered from this part of the hole.

Conditions changed below 30 m. First, signs of a heavy slush formation appeared. This was interpreted as indicating the level at which the porous, permeable firn transforms into bubbly

ice. When drilling in bubbly impermeable ice, all meltwater is retained in the hole. This situation required the concentration of the alcohol in the water-alcohol solution in the drilling column to be increased to prevent freezing of this solution as it mixed with freshly melted ice. Because of this condition, the concentration of the alcohol in the water-alcohol mixture was increased to 70% (see App. A). In spite of this, the next run after 30 m brought back the first full-length core—measuring 2.57 m, nearly as long as the length of the core container. Drilling to a depth of about 50 m proceeded smoothly. Approximately 2.5 m of core was recovered from each drilling run.

When drilling was resumed on 5 December 1978, difficulties were encountered. The diameter of the hole had decreased to nearly the same diameter as the drilling column, making for a tight hole. When dropped down freely, the drilling column descended at a speed of about 1 cm/s. In order to increase the diameter of the hole, the concentration of alcohol was increased to 75%. Drilling stopped for the night at a depth of 70.23 m. The next day (6 December), resumption of drilling also proved difficult because of the presence of slush that had formed during the night. The concentration of alcohol had to be decreased to 62% because of the increase of ice temperature. Coring proceeded smoothly. Drilling stopped for the night at a depth of 91.13 m.

At the beginning of drilling on 7 December, it was discovered that the drill hole contained a large amount of slush. When the drilling column, filled with pure alcohol, was dropped freely down the hole it took more than one and a half hours to travel from a depth of 50 m to the bottom of the hole even with the electrical power turned on to help penetrate the slush. Much of the slush was found in the core container when it was raised to the surface. As a precaution, the concentration of alcohol was kept at 65%. Drilling was stopped for the night at a depth of 119.76 m.

At this stage, it was decided to drill around the clock to avoid problems associated with the nighttime stops prior to 8 December. Two drilling teams were formed. The day shift was led by Yuriy Raikovsky (Institute of Geography, Moscow) and included two more assistants provided by RISP. The night shift was led by Victor Zagorodnov (Institute of Geography, Moscow) and

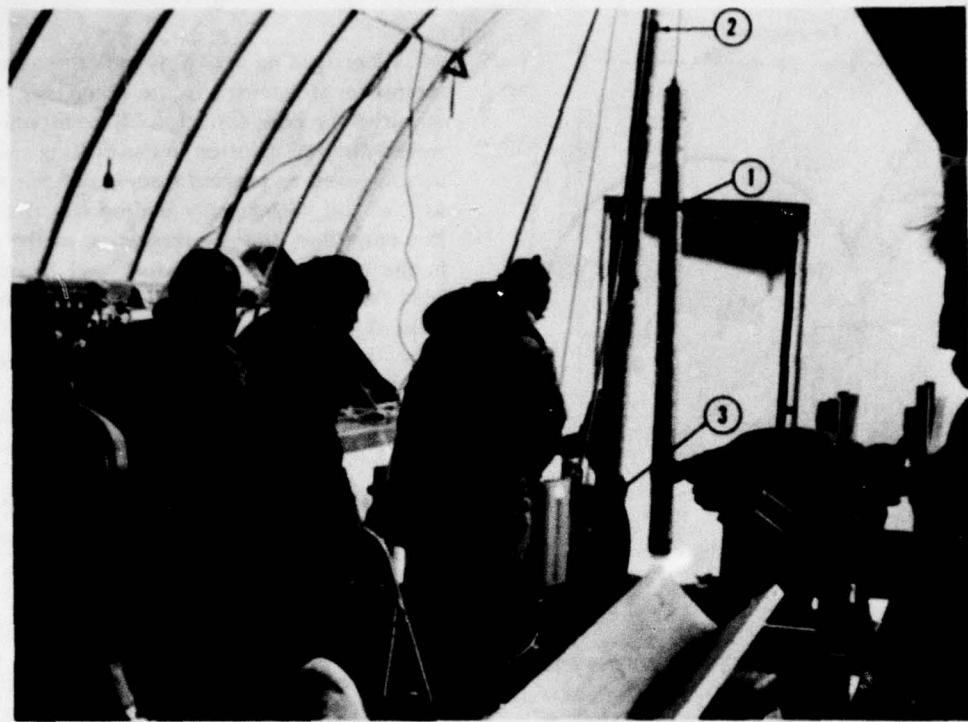


Figure 3. Drilling of antifreeze core hole at J-9 (1. drilling column; 2. mast; 3. winch.)

also included two additional assistants provided by RISP.

Difficulties were encountered at the beginning of drilling on 8 December between 50 m and 109 m, but below 109 m the drilling column descended more freely. The drilling proceeded nonstop until 13 December. The concentration of alcohol by this time had been steadily decreasing to about 40% at a depth of 400 m. At 409.97 m, a short-circuit occurred near where the electrical conductor was connected to the heating ring. At the same time the level of the alcohol-water solution within the hole rose dramatically from 65 m to 42 m from the surface.

A new drilling column with a 1.7-m long core container was attached to the drilling cable and drilling proceeded carefully. On the next trip, ice of completely different structure was recovered. This ice tasted salty and possessed structural features typical of old sea ice. All subsequent core possessed the same properties; some core

also contained inclusions of opaque brownish material.

At a depth of 416.04 m, or 6 m below the upper boundary of the brine ice, a special monitoring device showed that the drilling column was no longer lying on the bottom of the hole. The cable was released an extra 2 m but the drilling column did not encounter the bottom of the hole. It was now clear that the drilling column had penetrated the bottom of the Ross Ice Shelf. When the drilling column was lifted to the surface, it contained an ice core, the bottom of which contrasted sharply in structure to those of previous cores. The bottom of this core was flat with a waffle-like appearance and it formed sharp angles with the cylindrical side walls of the core. This surface clearly represented the bottom of the Ross Ice Shelf at J-9 (see cover photograph).

Figure 4 shows data on speed of drilling, the electrical power supplied and the daily depth log for the entire drilling at J-9.

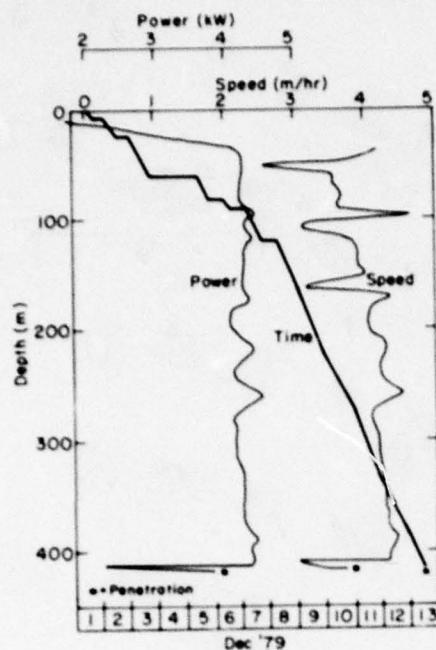


Figure 4. Power consumption, drilling speed, penetration rate and daily depth log for the entire drilling operation at J-9.

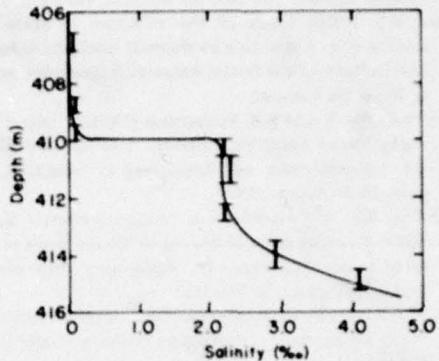


Figure 5. Distribution of core salinity in the bottom 10 m of the Ross Ice Shelf at J-9. Vertical data line represents length of core sampled; horizontal lines indicate spread of salinity values for several individual measurements.

#### PRELIMINARY DESCRIPTION OF THE CORE

A visual study of the ice cores indicates the existence of a three-layer structure to the Ross Ice Shelf at J-9. The first layer is composed of snow and firn and extends to a depth of about 40 m. Below this layer exists a homogeneous bubbly ice layer extending to 410-m depth.

The 6-m-thick bottom layer of ice has all the features of old sea ice formed by freezing at the bottom of the ice shelf. It contains vertical brine channels and some brownish inclusions. The salinity across the whole layer is about 2‰, which is many orders of magnitude saltier than the glacier ice located directly above this bottom layer. Figure 5 shows the core salinity for the bottom 10 m measured at CRREL by Dr. A.J. Gow.

Though the boundary between the glacial and sea ice layers is quite sharp, there does exist a thin and soft transitional zone between the two layers. This transitional layer, which is only a few

centimeters thick, consists of porous slushy ice. It is hydraulically connected to the sea below the layer of old sea ice, and the change of water level in the hole when the drilling column penetrated this zone is an indication of this fact.

The very bottom layer of old sea ice is composed of vertical ice crystals of about 3 cm in length and 5 mm in diameter. The ends of the crystals protrude downward into the sea water, giving rise to a waffle-like surface (see cover photograph). The sharp ends of the crystals protrude about 5 mm into the water.

The ice crystals of this bottom layer display a distinct alignment of brine plates within the horizontal plane. This alignment appears to be developed within the whole of the lower 6-m layer. Such alignment is consistent with observations of strong azimuthal orientations of crystal c-axes made on arctic sea ice by Cherapanov (1971) and Weeks and Gow (1978). Studies of the J-9 Camp ice cores are continuing at several institutions in the USA and USSR.

## LITERATURE CITED

Cherapanov, N.V. (1971) Spatial arrangement of sea ice crystal structure (in Russian). *Problemy Arktiki i Antarktiki*, vol. 38, p. 137-40.

Clough, J.W. and B.L. Hansen (1979) The Ross Ice Shelf Project. *Nature*, vol. 203, no. 4379, p. 433-435.

Ignatov, V.S. (1960) Study of the structure of snow and firn cover in Antarctica by thermal methods. *Information Bulletin of the Soviet Antarctic Expedition*, no. 21, p. 16-18. (in Russian).

Kovotkevich, Ye. S. and B.B. Kudriashov (1974) Ice sheet drilling by Soviet Antarctic expeditions. In *Ice core drilling* (J.F. Splettstoesser, ed.) University of Nebraska, Lincoln, 28-30 August, 1974.

Kudriashov, B.B., V.F. Fisenko, G.K. Stepanov and N.I. Bobin (1973) An experience of drilling in the ice sheet at Antarctica (in Russian). In *Antarctica Commission Reports*, Issue 12, p. 145-152.

Morev, V.A. (1966) Experimental electrothermal ice drilling at Mirny (in Russian). *Information Bulletin of the Soviet Antarctic Expedition* no. 56, p. 61-63.

Morev, V.A. (1972) A device for electrothermal core drilling. *Bulletin of Inventions and Discoveries* No. 27, License no. 350945 (in Russian).

Morev, V.A. and J.V. Raikovsky (1979) Core thermal drilling by Novolazarevskaya Station, Antarctica (in Russian). *Materialy Glaciologich Eskick Nabludeniy*, no. 34 (in press).

Ueda, H.T. and D.E. Garfield (1969) The USACRREL drill for thermal coring in ice. *Journal of Glaciology*, vol. 8, no. 53, p. 311-314.

Weeks, W.F. and A.J. Gow (1978) Preferred crystal orientations in the fast ice along the margins of the Arctic Ocean. CRREL Report 78-13.

Zotikov, I.A., A.P. Kapitsa, E.V. Kudriavsev and L.A. Sukhanov (1972) Thermal drilling of glaciers. *Antarctica Dokladii Comissii*, vol. 11, p. 141-156 (Russian).

**APPENDIX A. LOG OF CORE DRILLING THROUGH THE ROSS ICE SHELF (CAMP J-9).**

Trip no.	Core length (m)	Hole depth (m)	Voltage (volts)	Current (amps)	Time of drilling			Alcohol conc* wt (%)	Core diam (mm)
					Start (time)	End (time)	Duration (min)		
<i>1 December</i>									
1		1.5	150	6	2032	2043	11	40	
2		4.6	190	7	2050	2125	35	40	
<i>2 December</i>									
3			210	8	0959	1050	51	30	
4			230	8.5	1054	1130	36	30	
5			240	9	1137	1159	36	30	
6			220	9	1207	1218	11		
7	0.8		240	9	1230	1238	8		
8			250	9.5	1248	1328	40	30	
9		11	250	9.6	1338	1427	49	30	
10			250	9	1434	1524	40	30	
11			260	9.5	1532	1637	65	29	
12			270	10	1640	1728	48	29	
13			270	10	1735	1802	27	29	
<i>3 December</i>									
14			290	11	1048			70	
15			290	11	1246	1323	37	35	
16		32.39	300	11.5	1329	1407	38	35	
17	2.57	34.96	300	11.5	1422	1502	40	70	75-78
18	2.55	37.51	320	12	1507	1544	37	70	76-79
19	2.55	40.06	340	12.5	1552	1629	37	70	75-79
20	2.42	42.48	340	12.5	1635	1713	38	70	80.5-72
21	2.59	45.07	340	12.5	1720	1802	42	70	80-72
22	2.56	47.63	350	12.5	1808	1856	48	70	75-52
23	2.55	50.15	350	12.5	1902	2002	60	70	54-75
24	0.41	50.56	350	12.5	2013			70	78-79
<i>5 December</i>									
25	1.32	52.06	350	12.5	1426	1500	36	~75	73-75
26	2.66	54.72	350	12.5	1507	1555	48	75	70-78
27	2.67	57.39	350	12.5	1601	1646	45	75	74-79
28	2.58	59.97	350	12.5	1759	1742	43	75	
29	2.55	62.52	350	12.5	1756	1850	44	75	79-72
30	2.55	65.07	350	12.5	1848	1930	42	75	74-75
31	2.55	67.62	350	12.5	1939	2022	43	75	75-76
32	2.61	70.23	350	12.5	2030	2112	43	75	79-76
<i>6 December</i>									
33	0.44	70.67	350	13.0	0856	0904	10	~67	71-80.5
34	2.54	73.21	350	12.5	1106	1147	41	~67	75-80
35	2.55	75.76	350	12.5	1157	1240	43	62%	2°C 76-80
36	2.56	78.32	350	12.5	1249	1331	42	62	75-80
37	2.55	80.87	350	12.3	1340	1422	42	62	75-80
38	2.54	83.41	355	12.3	1430	1512	42	62	74-80
39	2.61	86.02	355	12.3	1522	1605	43	62	76-79
40	2.55	88.57	355	12.3	1613	1657	44	62	77-80
41	2.56	91.13	355	12.3	1712	1757	45	62	

Trip no.	Core length (m)	Hole depth (m)	Voltage (volts)	Current (amps)	Time of drilling			Alcohol conc.* wt (%)	Core diam (mm)
					Start (time)	End (time)	Duration (min)		
<i>7 December</i>									
42	0.49	91.62	355	12.3	0946	1002	16	59% 2°C	
43	2.51	94.13	350	12.3	1013	1058	45	100	75.80
44	2.58	96.71	350	12.3	1110	1155	45	65	75.80.5
45	2.59	99.30	350	12.3	1112	1245	33	65	75.79.5
46	2.58	101.88	355	12.3	1253	1338	45	65	76.80
47	2.49	104.46	355	12.3	1350	1437	47	65	74.79.5
47	2.56	107.02	355	12.5	1448	1530	42	65	
48	2.55	109.57	355	12.5	1542	1623	41	65	
49	2.55	112.19	355	12.5	1637		43	65	
50	2.56	114.68	355	12.5	1729	1810	41	65	
51	2.55	117.23	355	12.5	1822	1900	38	65	
52	2.53	119.76	355	12.5	1913	1953	40	80	
<i>8 December</i>									
53	2.54	122.30	360	12	0800	0839	39	~70% 0°C	76.80
54	2.54	124.84	345	12.5	0857	0937	40	~70	76.80
55	2.54	122.38	350	12.3	0952	1032	40	59	79.75.5
56	2.55	129.93	350	12.3	1047	1126	39	59	
57	2.54	132.47	350	12.3	1139	1219	40	59	
58	2.53	135.00	350	12.3	1234	1313	39	59	
59	2.54	137.54	350	12.3	1327	1410	43	59	
60	2.54	140.08	350	12.3	1420	1500	40	59	
61	2.55	142.63	350	12.3	1513	1555	42	59	
62	2.54	145.17	345	12.0	1610	1650	40	59	
63	2.53	147.70	350	12.3	1943	2023	40	59	80.5.79
64	2.54	150.24	355	12.5	2032	2110	38	59	79.5.78
65	2.55	152.79	350	12.5	2123	2201	38	59	80.5.78
66	2.54	155.33	350	12.5	2212	2253	41	59	80.78
67	2.55	157.88	350	12.3	2304	2343	39	59	80.5.78
68	2.05	159.93	350	12.3	2355	0034	39	59	80.5.78
<i>9 December</i>									
69	2.35	162.28	350	12.3	0050	0131	41	59	79.78
70	2.52	164.80	350	12.3	0147	0232	45	59	
71	2.53	167.33	350	12.3	0292	0322	40	65	
72	2.65	169.98	350	12.3	0347	0426	39	65	
73	2.41	172.39	350	12.5	0520	0527	07	59	
74	0.54	172.93	350	12.5	0545	0631	46	80	
75	2.44	175.37	340	12	0652	0731	39	63	
76	2.56	177.93	340	12	0746	0825	39	63	
77	2.56	180.49	340	12	0850	0928	38	63	
78	2.44	182.93	340	12	0950	1027	37	63	
79	2.55	185.48	340	12	1048	1137	49	63	
80	2.53	188.01	340	12	1200	1240	40	63	
81	2.50	190.51	340	12		1340		63	
82	2.53	193.04	340	12	1405	1446		63	
83	2.55	195.61	340	12	1503	1548	45	63	
84	2.54	198.15	340	12	1610	1653	43	63	
85	2.64	200.79	340	12	1715	1800	45	63	
86	2.53	203.32	340	12	1835	1921	46	63	
87	2.54	205.86	360	12.5	1961	2022	41	60	75.75.5
88	2.53	208.39	345	12.3	2037	2115	38	60	77.75
89	2.48	210.87	345	12.3	2131	2212	41	60	77.80
90	2.54	213.41	345	12.3	2227	2305	38	60	75.78
91	2.54	215.95	345	12.3	2320	2358	38	60	78.8.76

Trip no.	Core length (m)	Hole depth (m)	Voltage (volts)	Current (amps)	Time of drilling			Alcohol conc* wt %	Core diam (mm)
					Start (time)	End (time)	Duration (min)		
<i>10 December</i>									
92	2.52	218.47	345	12.3	0013	0055	42	60	79.75.5
93	2.58	221.05	350	12.5	0110	0152	42	59	78.74.5
94	2.54	223.59	350	12.5	0207	0247	40	59	78.76.5
95	2.61	226.20	350	12.5	0302	0344	42	59	77.5.75
96	2.56	228.76	350	12.5	0358	0441	43	57	80
97	2.00	231.35	340	12.3	0455	0531	36	57	78.72
98	2.57	233.93	345	12.3	0547	0629	42	57	78
99	2.50	236.43	350	12.3	0645	0730	45	57	75.78
100	2.52	238.95	345	12.2	0753	0830	37	57	
101	2.51	241.46	345	12.3	0852	0932	40	57	
102	2.54	244.00	340	12.1	0958	1040	42	56	
103	2.56	246.56	345	12.3	1102	1142	40	56	
104	2.54	240.10	345	12.3	1202	1255	53	56	75.78
105	2.55	251.65	350	12.5	1317	1353	36	56	
106	2.53	254.18	350	12.5	1417	1433	36	56	
107	2.55	256.73	350	12.5	1520	1555	35	55	
108	2.53	259.26	355	12.8	1632	1707	35	55	
109	2.54	261.80	350	12.5	1742	1820	38	55	
110	2.54	264.34	350	12.5	1840	1914	34	55	79.5.78
111	2.54	266.88	350	12.7	2028	2101	33	55	
112	2.54	269.72	340	12.2	2119	2154	35	53.5	79.5.77
113	2.53	271.95	340	12.2	2211	2245	34	53.5	
114	2.54	274.49	340	12.2	2304	2338	34	53.5	79.5.77
<i>11 December</i>									
115	2.55	277.04	340	12.2	2354	0028	34	51.5	80.78
116	2.55	279.59	340	12	0045	0120	35	51.5	80.77
117	2.33	281.92	340	12	0137	0210	33	51.5	80
118	2.62	284.54	340	12	0236	0212	36	56.5	
119	2.53	287.07	340	12	0320	0405	35	56.5	
120	2.54	289.61	340	12.3	0424	0458	34	56.5	78.77
121	2.55	292.16	338	12	0515	0550	35	53	
122	2.53	294.69	340	12.3	0607	0644	37	53	78
123	2.53	297.22	340	12.3	0703	0740	37	53	75.78
124	2.53	299.75	340	12.3	0806	0842	36	53	
125	2.73	302.48	345	12.3	0905	0940	35	53	
126	2.53	305.01	340	12.2	1002	1037	35	53	
127	2.56	307.57	340	12.2	1101	1137	36	53	
128	2.53	310.10	340	12.2	1159	1234	35	52	
129	2.54	312.64	340	12.2	1259	1333	34	52	
130	2.52	315.16	345	12.3	1357	1430	33	52	
131	2.51	317.67	345	12.3				52	
132	2.52	320.19	345	12.3	1554	1628	34	53	
133	2.55	322.74	345	12.3	1652	1726	34	50	
134	2.52	325.26	345	12.3	1752	1825	33	50	
135	2.52	327.78	345	12.5	1850	1921	31	50	
136	2.54	330.32	345	12.5	1960	2016	36	50	
137	2.56	332.86	345	12.5	2035	2110	35	50	
138	2.54	335.60	345	12.5	2125	2200	35	50	
139	2.53	337.93	345	12.5	2219	2255	36	50	
140	2.54	340.47	345	12.5	2314	2340	27	50	77

Trip no.	Core length (m)	Hole depth (m)	Voltage (volts)	Current (amps)	Time of drilling			Alcohol conc* wt %	Core diam (mm)
					Start (time)	End (time)	Duration (min)		
<b>12 December</b>									
141	2.54	343.01	345	12.5	0015	0051	36	51	
142	2.51	345.52	345	12.5	0111	0145	34	51	
143	2.54	348.06	345	12.5	0205	0232	32	51	
144	2.55	350.61	345	12.5	0257	0328	31	51	
145	2.54	353.15	345	12.5	0347	0422	34	51	
146	2.54	355.69	345	12.5	0440	0511	31	51	
147	2.58	358.27	345	12.5	0531	0611	40	51	
148	2.54	360.81	345	12.5	0630	0706	36	51	
149	2.54	363.35	345	12.5	0733	0808	35	50	
150	~2.54	365.89	345	12.5	0834	0910	36	50	76.71
151	~2.54	368.43	345	12.5	0937	1015	37	50	70.78
152	1.00	369.43	345	12.5	1040	1120	40	50	
153	2.50	371.93	345	12.5	1157	1242	~45	50	
154	2.50	374.43	345	12.5	1612	1657	45	50	
155	2.53	376.96	345	12.5	1724	1812	48	50	
156	2.54	379.50	345	12.5	1838	1927	49	50	
157	2.54	382.04	345	12.5	1943	2023	40	49	
158	2.54	386.58	345	12.5	2047	2128	41	49	
159	2.54	387.12	350	12.7	2147	2224	37	41	
160	2.54	389.66	350	12.8	2242	2318	36	45	75.8-72.8
161	2.54	392.20	350	12.8	2337	0012	35	42	
<b>13 December</b>									
162	2.54	394.74	350	12.8	0034	0107	33	42	
163	2.58	397.32	345	12.5	0126	0159	33	40	78
164	2.54	399.36	345	12.5	0218	0249	31	40	78.76.5
165	2.54	402.40	345	12.5	0307	0342	35	39	76.45-76.20
166	2.54	404.94	345	12.5	0401	0435	34	39	77.8-73.15
167	2.54	407.48	372	12.5	0455	0538	43	39	
168	2.49	409.97	342	12.5	0553	0637	40	41	
169	1.54	411.51	240	13	0814	0855	41	41	
170	1.51	413.02	240	13	0920	0953	33	41	
171	1.71	414.63	240	13	1013	1047	34	41	
172	1.41	416.04	260	14.5	1110	1133	23	28	

\*In core container

\*U.S. GOVERNMENT PRINTING OFFICE: 1979-602-400/303